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ON EMBRITTLEMENT OF A COBALT-BASE ALLOY (L-605)

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INTRODUCTION

The cobalt-base alloy L-605 (HS-25) has many elevated temperature uses. Its mechanical and physical properties are summarized in references 1 and 2. Because of its elevated temperature strength, fabricability, and, weldability, the alloy is of interest for aerospace applications. A potential application is its use in tubing and radiator components of advanced space power systems that are required to operate for mission times of thousands of hours. It has been observed (ref. 3), however, that this alloy has a tendency to become brittle after long-time exposure to high temperatures. This property is obviously undesirable in engineering applications involving long-time, high-temperature use, particularly those subject to mechanical and thermal cycling.

Jenkins (ref. 3) attributed the embrittlement of L-605 to the heavy precipitation of the intermetallic compound Co_2W during high-temperature exposure. Wlodek (ref. 4) suggested that the compound Co_2W is a stable Laves phase in this alloy. Because Co_2W is not an equilibrium phase in the Co-W binary system (ref. 5), Wlodek suggested that it is stabilized in L-605 by the silicon present. He contended that reduction in silicon content would lessen Laves phase precipitation and, in turn, reduce embrittlement. Some data supporting this contention are shown in references 4 and 6. It was also proposed in reference 4 that precipitation of carbides and the possible formation of hcp cobalt contributed to the

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embrittlement in L-605 and that the formation of hcp cobalt can be prevented by increasing the concentration of iron. Iron is believed to stabilize the fcc cobalt structure.

In view of the importance of retaining ductility in L-605, a program was undertaken at NASA Lewis Research Center to investigate the effect of wide variations of Si and Fe content within the manufacturer's specifications on the room-temperature ductility, as measured by tensile elongation, of L-605 after aging.

INVESTIGATIVE PROCEDURE

Six special heats and two commercial heats, based on the manufacturer's standard practice prior to 1964, were obtained from the Union Carbide Stellite Company for use in this investigation. This manufacturer's commercial melting practice has recently been changed to provide this alloy with low silicon contents similar to those obtained in the low silicon special heats of this investigation. Table I gives the nominal composition limits of L-605 as well as the silicon and iron contents and grain sizes of the heats investigated. Silicon and iron contents were determined by an independent laboratory for all heats except heat 5. In the latter case the analysis shown was determined by the supplier. All material was hot-rolled to approximately 0.050 inch sheet and mill-annealed (2250° F, rapid-air cooled) by the supplier. Tensile specimens were machined and then aged at 1600° F in air. This temperature was selected because the greatest rate of embrittlement was observed (ref. 4) with material that had been aged at this temperature. After aging, the specimens were cooled in air to room temperature, where tensile tests were performed. A 1-inch gage length was used to measure elongation.

RESULTS AND DISCUSSION

The average room-temperature ductilities before aging and after aging at 1600° F for 50, 200, and 1000 hours are shown in figure 1. For purposes of comparison the heats may roughly be divided into two groups: high silicon content (0.49 to 1.00 percent) and low silicon content (0.12 and 0.23 percent). At all aging times the three heats with the low silicon content had substantially greater tensile ductility than did the five high silicon content heats. After aging 50 hours, the low silicon heats had elongations that ranged from approximately 24 to 34 percent while the elongations of the high silicon heats ranged between about 8 percent and 14 percent. After 200 hours aging the elongations of the low silicon heats ranged from approximately 17 to 32 percent as compared with only 3 to 7 percent for the high silicon heats. After aging 1000 hours, the low silicon heats still had considerably greater ductility, 13 to 16 percent, as against 2 to 6 percent for the high silicon heats. Four of the five high silicon heats had elongations ranging between approximately 2 and 3 percent.

The highest silicon content heat (heat 6) did not always show the lowest ductility nor did both of the lowest silicon content heats (7 and 8) always have the greatest ductility. Some crossover of the curves occurs so that the exact ranking of heats by ductility is not the same at each aging time. However, the trend toward improved ductility with lower silicon content is unmistakable, and a pronounced increase in ductility is clearly obtainable by a reduction in silicon content to between 0.12 and 0.23 weight percent. This is illustrated more markedly in figure 2, which presents the relation between ductility and silicon content for all heats after aging for 1000 hours. Reducing the silicon content from 1 to 0.49 percent does not appear to have a pronounced effect on ductility. However, further reductions in silicon content to 0.23 percent or less resulted

in ductilities appreciably higher than those obtained with heats containing 0.49 to 1.00 percent silicon.

When heats within a narrow composition range of iron (0.16 to 0.57 percent) are considered, ductility after 200- and 1000-hour aging treatments is still seen to increase with decreasing silicon content (fig. 1). On the other hand, when heats within narrow composition ranges of silicon (0.12 to 0.23 and 0.49 to 0.060 percent) are considered, no consistent trend of increasing ductility with increasing iron content is observed. In general, then, little apparent effect on post aging ductility was observed as a result of variations in iron content from 0.16 to 3.24 percent.

The tensile tests also indicated that tensile strength was not adversely affected by reduced silicon content. In fact, after aging 1000 hours at 1600° F, the low silicon heats had tensile strengths equal to or slightly higher than those of the two commercial heats.

The microstructure after aging showed that substantially less precipitation occurred in heats that were low in silicon as compared with heats that were high in silicon. Figure 3 provides a typical illustration of this. Variations in iron content, on the other hand, appeared to have little effect on the microstructure after aging. It should also be noted that X-ray diffraction studies by Wlodek on samples used in this investigation indicated that reducing silicon content resulted in substantial reductions in the amount of Laves phase present after aging (ref. 6). Thus it is evident from this investigation that the post aging ductility of L-605 can be substantially improved by reducing silicon content and that the improved ductility is associated with a reduction in the amount of Laves phase precipitation.

SUMMARY OF RESULTS

1. Reduction of silicon content to 0.23 percent, or less, substantially increased the room-temperature ductility of L-605 after long-time aging at 1600° F. This improved ductility was achieved without loss in room-temperature tensile strength.

2. Considerably less precipitation occurred in heats that were low in silicon content (0.12 to 0.23 percent) as compared with those that were high in silicon content (0.49 to 1.00 percent).

3. Variations in iron content from 0.16 to 3.24 percent had little apparent effect on post aging microstructure or ductility.

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TABLE I. - HEATS INVESTIGATED

[Manufacturer's composition limits for L-605 are 19 to 21 Cr, 14 to 16 W, 9 to 11 Ni, 1 to 2 Mn, 0.05 to 0.15 C, 3 max Fe, 1 max Si, balance Co (ref. 1)]

Heat number	1	2	3	4	5	6	7	8
Silicon content, weight percent	0.23	0.60	0.73	0.55	0.49	1.00	0.12	0.12
Iron content, weight percent	0.57	0.49	0.24	1.60	1.85	3.24	0.16	3.06
ASTM average grain size	6	6	5	4	4	6	6	6

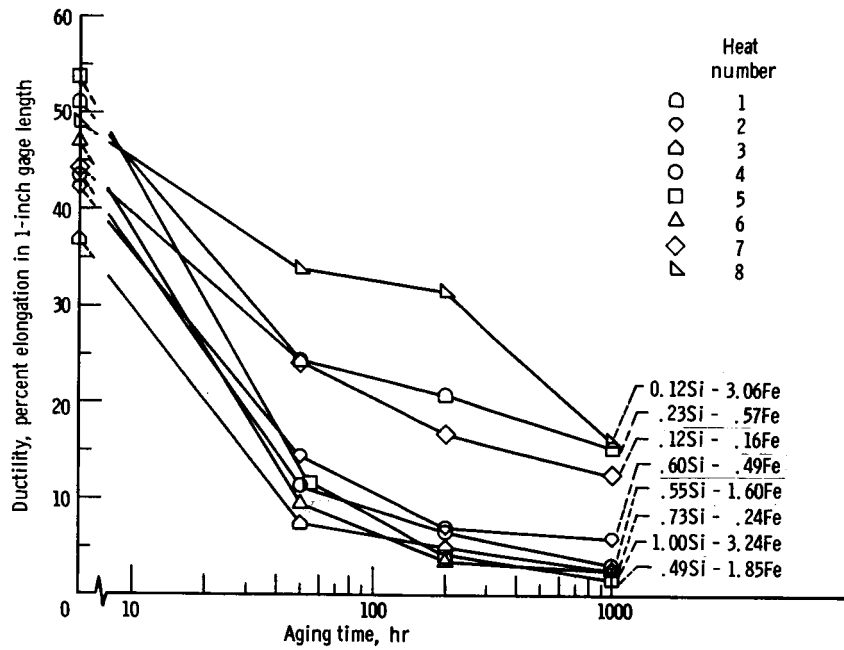


Figure 1. - Effect of aging time at 1600° F on average room-temperature ductility.

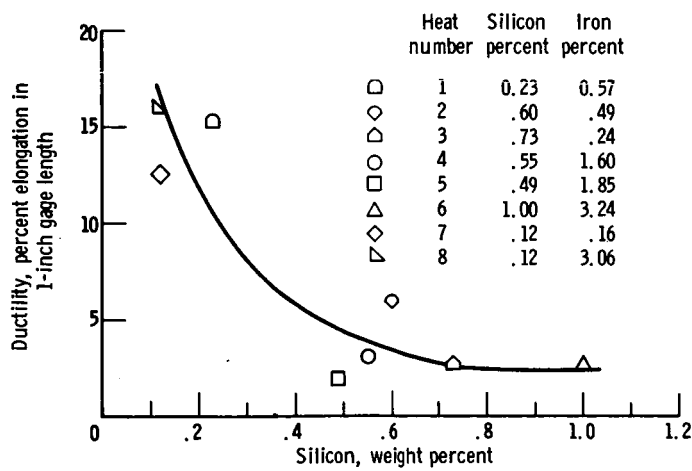
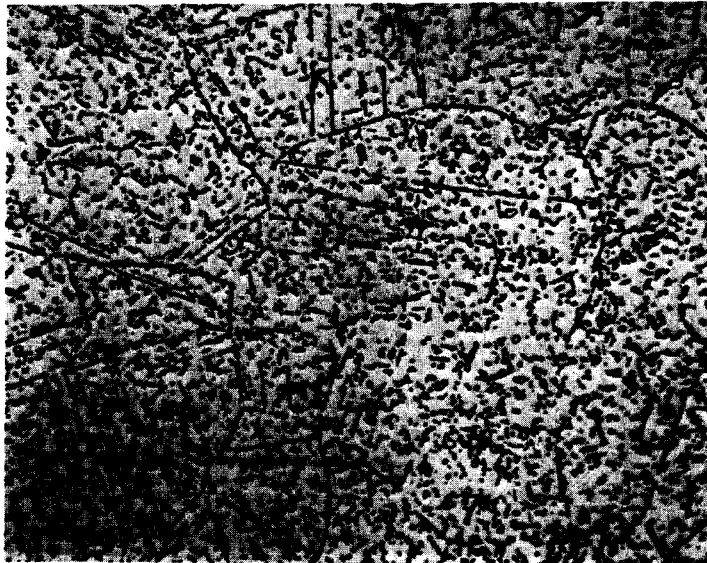
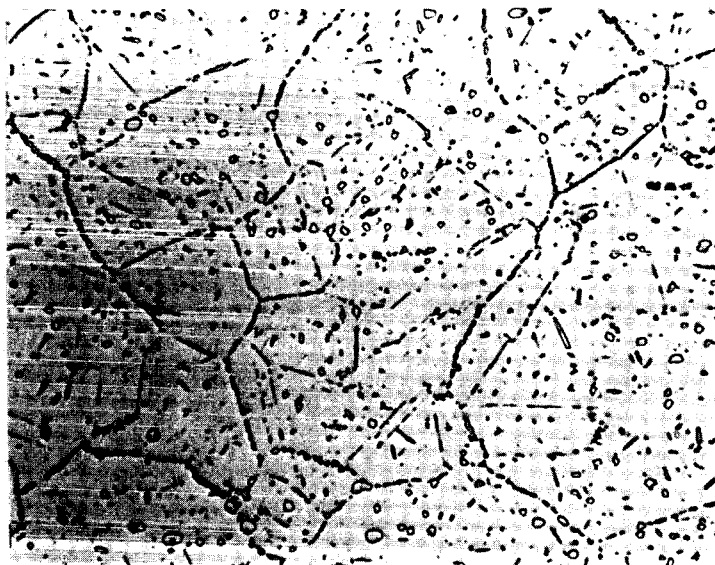


Figure 2. - Effect of silicon content on average room-temperature ductility after aging 1000 hours at 1600° F.



(a) 0.73 Percent silicon (heat 3).



(b) 0.12 Percent silicon (heat 7).

Figure 3. - Effect of silicon content on microstructure of L-605 after aging 1000 hours at 1600° F; iron content of both heats are essentially the same.